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The Chandra Deep Survey of the Hubble Deep Field North Area. II. Results from the Caltech Faint Field Galaxy Redshift Survey Area[1]

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[1]Based on observations obtained at the W. M. Keck Observatory which is operated jointly by the California Institute of Technology and the University of California. Based on observations obtained by the Hobby-Eberly Telescope, which is a joint project of The University of Texas at Austin, The Pennsylvania State University, Stanford University, Ludwig-Maximillians-Universität München, and Georg-August-Universität Göttingen.

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abstract

A deep X-ray survey of the Hubble Deep Field North (HDF-N) and its environs is performed using data collected by the Advanced CCD Imaging Spectrometer (ACIS) on board the *Chandra X-ray Observatory*. Currently a 221.9 ks exposure is available, the deepest ever presented, and here we give results on X-ray sources located in the $8.6' \times 8.7'$ area covered by the Caltech Faint Field Galaxy Redshift Survey (the "Caltech area"). This area has (1) deep photometric coverage in several optical and near-infrared bands, (2) extensive coverage at radio, submillimeter and mid-infrared wavelengths, and (3) some of the deepest and most complete spectroscopic coverage ever obtained. It is also where the X-ray data have the greatest sensitivity; the minimum detectable fluxes in the 0.5–2 keV (soft) and 2–8 keV (hard) bands are $\approx 1.3 \times 10^{-16}$ erg cm^{-2} s^{-1} and $\approx 6.5 \times 10^{-16}$ erg cm^{-2} s^{-1}, respectively. More than $\approx 80\%$ of the extragalactic X-ray background in the hard band is resolved.

The 82 *Chandra* sources detected in the Caltech area are correlated with more than 25 multiwavelength source catalogs, and the results of these correlations as well as spectroscopic follow-up results obtained with the Keck and Hobby-Eberly Telescopes are presented. All but nine of the *Chandra* sources are detected optically with $R \lesssim 26.5$. Redshifts are available for 39% of the *Chandra* sources, including 96% of the sources with $R < 23$; the redshift range is 0.1–3.5, with most sources having $z < 1.5$. Eight of the X-ray sources are located in the HDF-N itself, including two not previously reported. A population of X-ray faint, optically bright, nearby galaxies emerges at soft-band fluxes of $\lesssim 3 \times 10^{-16}$ erg cm^{-2} s^{-1}.

Our multiwavelength correlations have set the tightest constraints to date on the X-ray emission properties of μJy radio sources, mid-infrared sources detected by *ISO*, and very red ($\mathcal{R} - K_s > 5.0$) objects. Sixteen of the 67 1.4 GHz μJy sources in the Caltech area are detected in the X-ray band, and the detection rates for starburst-type and AGN-candidate μJy sources are comparable. Only two of the 17 red, optically faint ($I > 25$) μJy sources are detected in X-rays. While many of the starburst-type μJy sources appear to contain obscured AGN, the *Chandra* data are consistent with the majority of the μJy radio sources being powered by star formation. Eleven of the ≈ 100 *ISO* mid-infrared sources found in and near the HDF-N are detected in X-rays. In the HDF-N itself, where both the infrared and the X-ray coverage are deepest, it is notable that six of the eight *Chandra* sources are detected by *ISO*; most of these are known to be AGN where the X-ray and infrared detections reveal both the direct and indirect accretion power being generated.

The high X-ray to infrared matching rate bodes well for future sensitive infrared observations of faint X-ray sources.

Four of the 33 very red objects that have been identified in the Caltech area by Hogg et al. (2000a) are detected in X-rays; these four are among our hardest *Chandra* sources, and we argue that they contain moderately luminous obscured AGN. Overall, however, the small *Chandra* detection fraction suggests a relatively small AGN content in the optically selected very red object population. A stacking analysis of the very red objects not detected individually by *Chandra* yields a soft-band detection with an average soft-band X-ray flux of $\approx 1.9 \times 10^{-17}$ erg cm^{-2} s^{-1}; the observed emission may be associated with the hot interstellar media of moderate redshift elliptical galaxies.

Constraints on AGN candidates, extended X-ray sources, and Galactic objects in the Caltech area are also presented.